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PROCESSING EFFECTS ON SHCOTTKY BARRIER HEIGHTS FOR THREE TERMIN--ETC(U)
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UNCLASSIFIED AFOSR-TR-77-0860 NL

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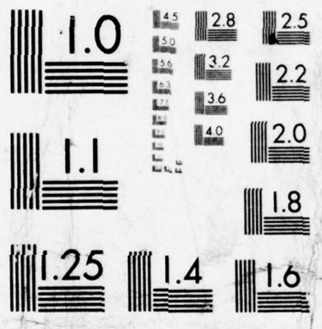
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5.0
5.6

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AFOSR-TR- 77-0860

(12)

PROCESSING EFFECTS ON SCHOTTKY BARRIER HEIGHTS FOR THREE TERMINAL TRANSFERRED ELECTRON DEVICES

AFOSR GRANT-76-3053

Research Objectives

The purpose of this research project was to examine the effects of material processing on the Schottky barrier height of gold and aluminum to gallium arsenide (GaAs). Specific goals consisted of the following:

1. Establish current-voltage (I-V), capacitance-voltage (C-V), and current-temperature (I-T) measurement capability.
2. Write computer routines for data analysis and graphic presentation.
3. Establish a base line by measurements on samples from various sources and with differing preparations.
4. Run controlled matrix experiments on samples doped mid 10^{17} cm^{-3}, mid^{16} cm^{-3}, and mid 10^{15} cm^{-3}.
5. Develop a mathematical and physical model to examine leakage current, surface states, and actual barrier height in non-guard ring type samples.

Accomplishments

Objective 1

Current-voltage measurements were made on a Keithley Model 601 Electrometer using a regulated power supply and two Data Precision Model 1450 four digit accuracy multimeters. Current-temperature was measured with the same equipment and a copper-constantan calibrated thermocouple reachout system. The thermocouple was in contact with the sample and covered by a bead of parafin oil for improved thermal contact.

Capacitance-voltage measurements were made on a Tektronix Model 130 L-C Meter using a calibrated Heathkit Model 1B-101

(See 1473)

frequency counter. A Data Precision Model 1450 was used for voltage measurement.

Initial calibration measurements were made on some GaP light emitting diodes whose properties had previously been measured at General Electric's Research and Development Center and Lighting Research Laboratory.

Objective 2

Computer routines were written for I-V, C-V, and I-T data analysis and graphic presentation. The routines were checked by running artificial "ideal" data derived from the formulas used. Appendix 2 contains a listing of these programs. The graphics portion (Graphical Display System/ University of California, Berkeley) is available on request.

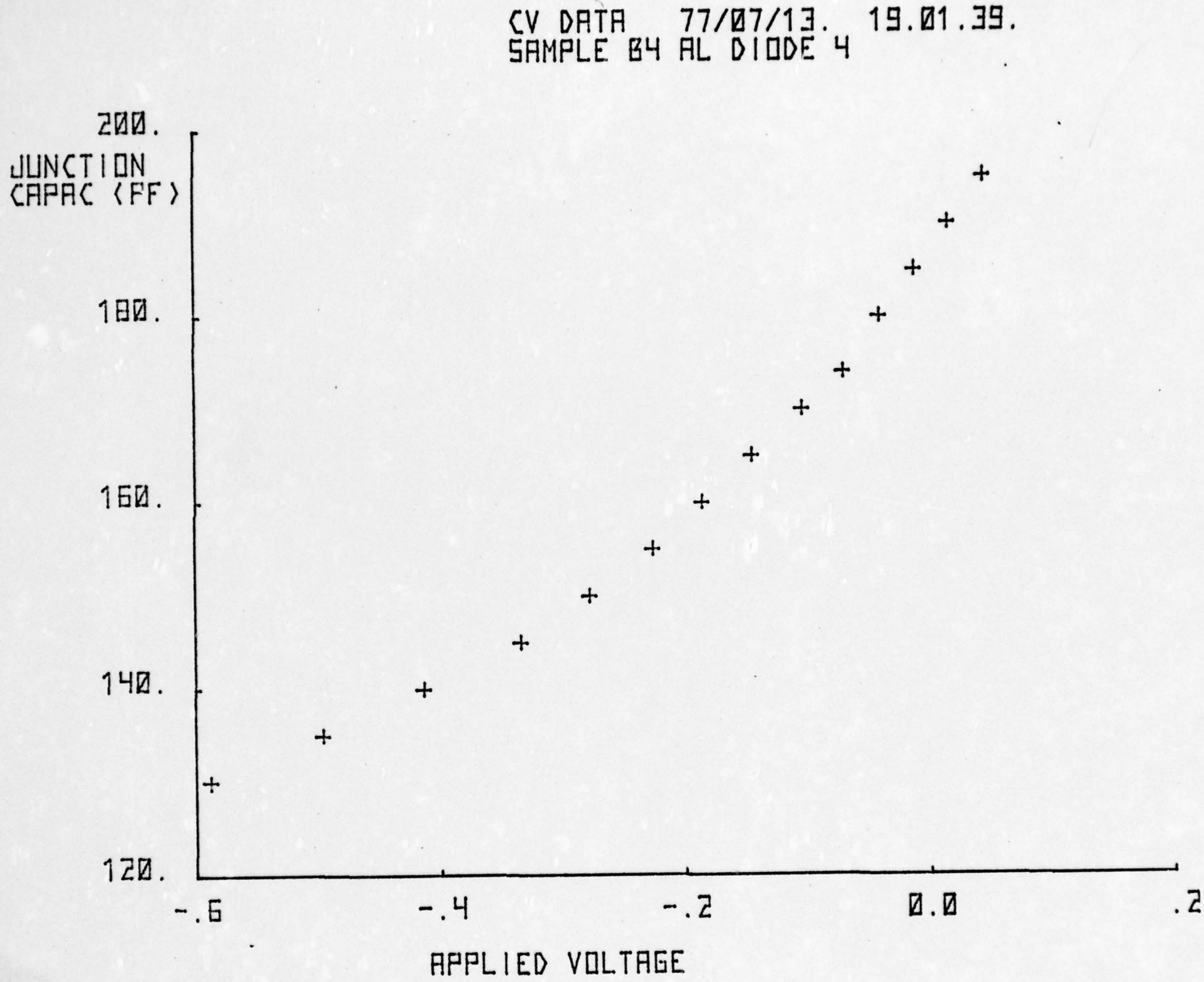
Objective 3

Samples for analysis were obtained from the Avionics Laboratory and Materials Laboratory at Wright-Patterson Air Force Base and purchased from Laser Diode Laboratories. Table 1 presents a list of the samples measured and their origin. Initial measurements concentrated on C-V. These measurements indicated major problems with leakage current and so later emphasis was placed on I-V with a few I-T measurements to gain additional information.

Figures 1 through 11 illustrate the type of data obtained and its output format from the computer. Table 2 summarizes the data obtained in establishing a baseline. The following observations were made on the data.

TABLE 1

Sample	Origin	Orientation	EPD (cm^{-3})	Dopant	$\mu(cm^2/V\text{-}sec)$	$N(cm^{-3})$
B1, B2, B3, B4	Laser Diode Labs	(100)	3500	Te	3468	.66 E18
N19A, B, C	AFML/WPAFB	3^o off (100) toward (100)	--	Te	--	2.5 E18
RCA	AFAL/WPAFB	(100)	--	--	--	1×10^{16} on n+
C1, C3	Laser Diode Labs	(100)	1400	Si	1969	1.4 E18
TI	AFAL/WPAFB	(100)				n+on n


CV DATA 77/07/13. 19.01.39.
SAMPLE 64 AL DIODE 4
200.
JUNCTION
CAPAC (FF)
180.
160.
140.
120.
-.6
-.4
-.2
0.0
.2
APPLIED VOLTAGE

SAMPLE B4 AL DIODE 4
77/07/13.   19.01.39.

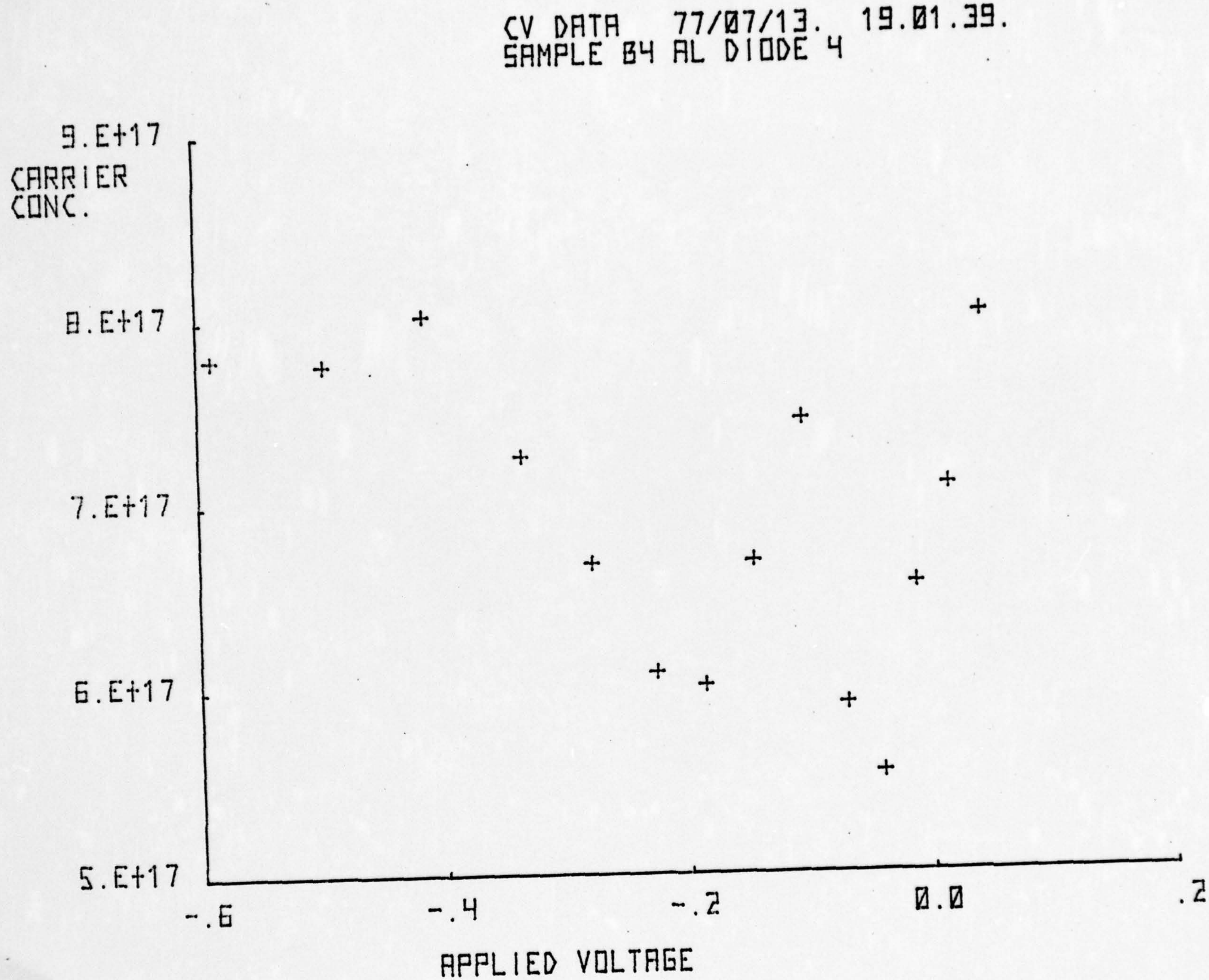
MATERIAL GAAS   AREA   .05965500 MM↑2

TEMP 300.0   JUNCTION TYPE ABRUPT

V (VOLTS)	C (PF)	DENSITY (NO./CM↑3)
-.588	130.000	7.798E+17
-.496	135.000	7.766E+17
-.414	140.000	8.028E+17
-.335	145.000	7.260E+17
-.278	150.000	6.681E+17
-.226	155.000	6.088E+17
-.186	160.000	6.016E+17
-.145	165.000	6.689E+17
-.104	170.000	7.453E+17
-.070	174.000	5.908E+17
-.041	180.000	5.538E+17
-.012	185.000	6.562E+17
.016	190.000	7.089E+17
.045	195.000	8.018E+17

BUILT IN V = .549   AVERAGE DENSITY = 6.882E+17

Fig. 2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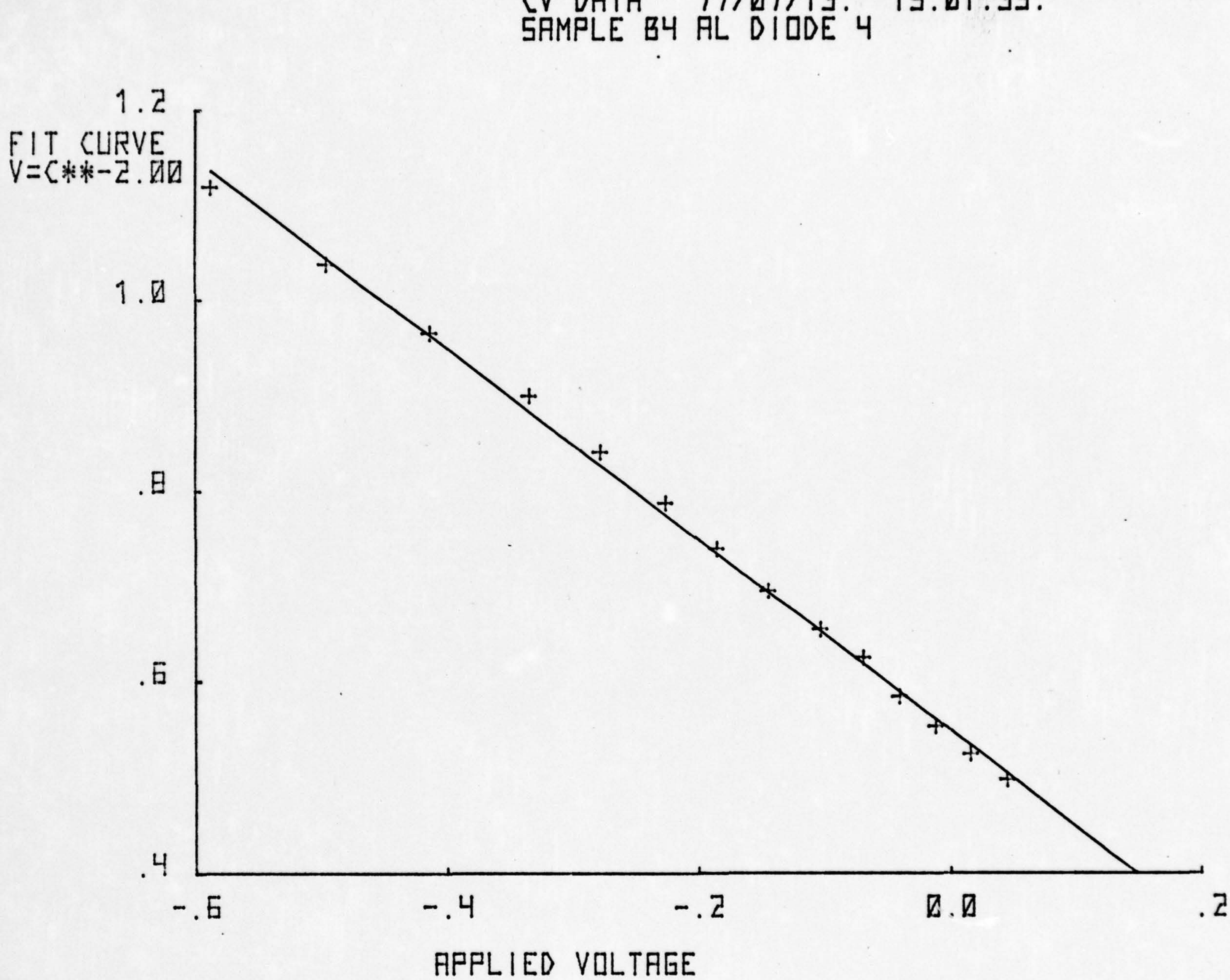
SAMPLE B4 AL DIODE 4
9.E+17
CARRIER
CONC.
8.E+17
7.E+17
6.E+17
5.E+17
-.6
-.4
-.2
0.0
.2
APPLIED VOLTAGE

Fig. 3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SAMPLE B4 AL DIODE 4
FIT CURVE
V=C**-2.00
1.2
1.0
.8
.6
.4
-.6
-.4
-.2
0.0
.2
APPLIED VOLTAGE

Fig. 4

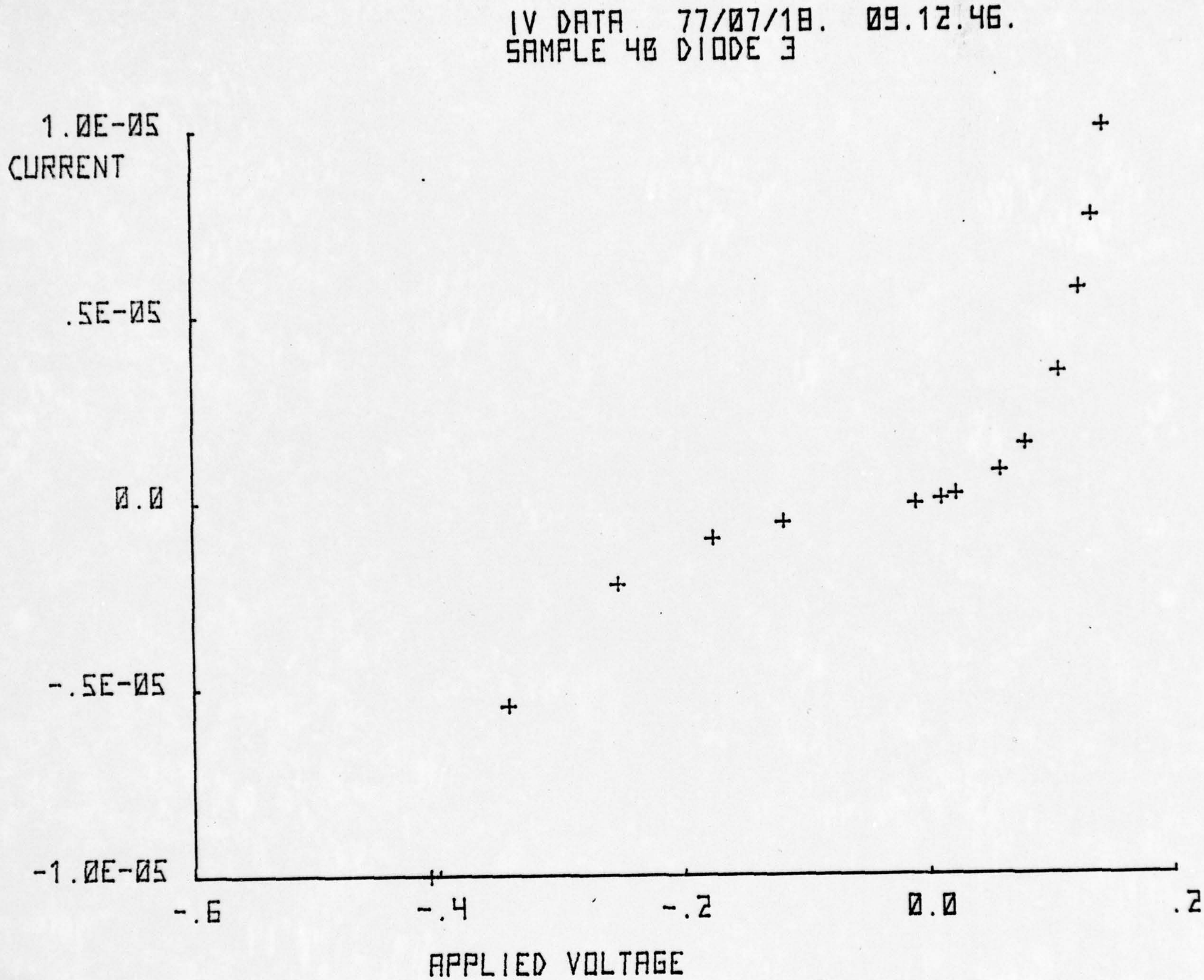

IV DATA 77/07/18. 09.12.46.
SAMPLE 48 DIODE 3
1.0E-05
CURRENT
.5E-05
0.0
-.5E-05
-1.0E-05
-.6
-.4
-.2
0.0
.2
APPLIED VOLTAGE

Fig. 5

SAMPLE 4B DIODE 3
77/07/18. 09.12.46.

MATERIAL GAAS AREA .05965500 MM↑2

TEMP 27.0 JUNCTION TYPE ABRUPT

I (AMPS)	V (VOLTS)
-1.000E-05	-.4079
-5.450E-06	-.3437
-2.184E-06	-.2534
-9.710E-07	-.1756
-5.280E-07	-.1185
-5.370E-08	-.0102
8.250E-08	.0110
1.920E-07	.0230
8.080E-07	.0596
1.540E-06	.0803
3.470E-06	.1080
5.700E-06	.1250
7.630E-06	.1355
1.000E-05	.1430

THE EXPONENTIAL CURVE FIT GIVES:
I = A * (EXP(Q*V/(K*T)*1/N)-1)
WITH:
A = 4.0500E-04
N = 1.5672
AND SERIES RESISTANCE OF -.4270
ASSUMING THAT THE EFFECTIVE RICHARDSON CONSTANT
IS 120.0; THE CALCULATED BUILT IN VOLTAGE IS .6204

THE LINEAR CURVE FIT GIVES:
I=A * EXP(Q*V/(K*T)*1/N)
WITH:
A = 2.6657E-04
N = 1.3541
AND A BUILT IN VOLTAGE OF .6312

Fig. 6

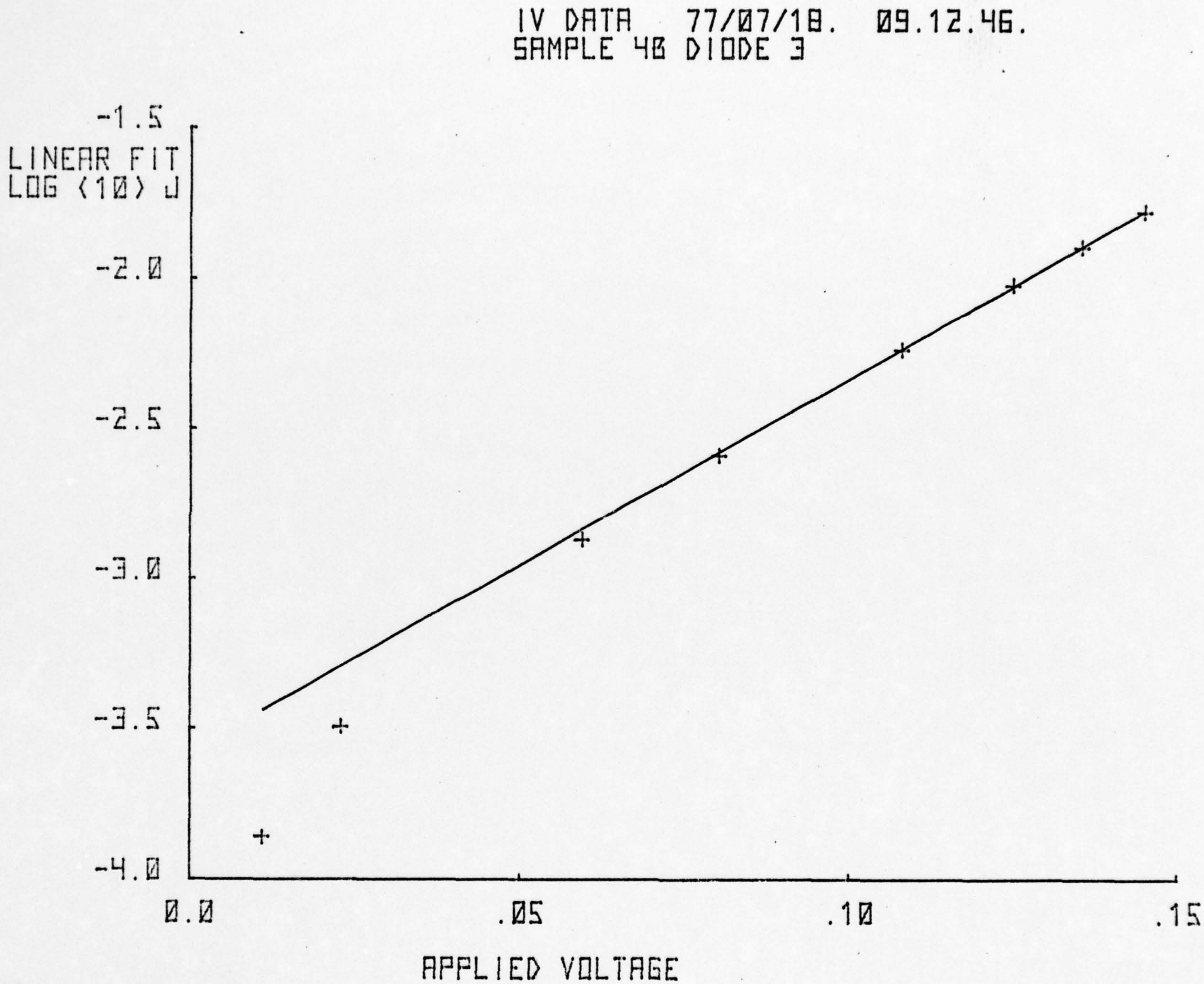

IV DATA 77/07/18. 09.12.46.
SAMPLE 40 DIODE 3
LINEAR FIT
LOG (10) J
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
0.0
.05
.10
.15
APPLIED VOLTAGE

Fig. 7

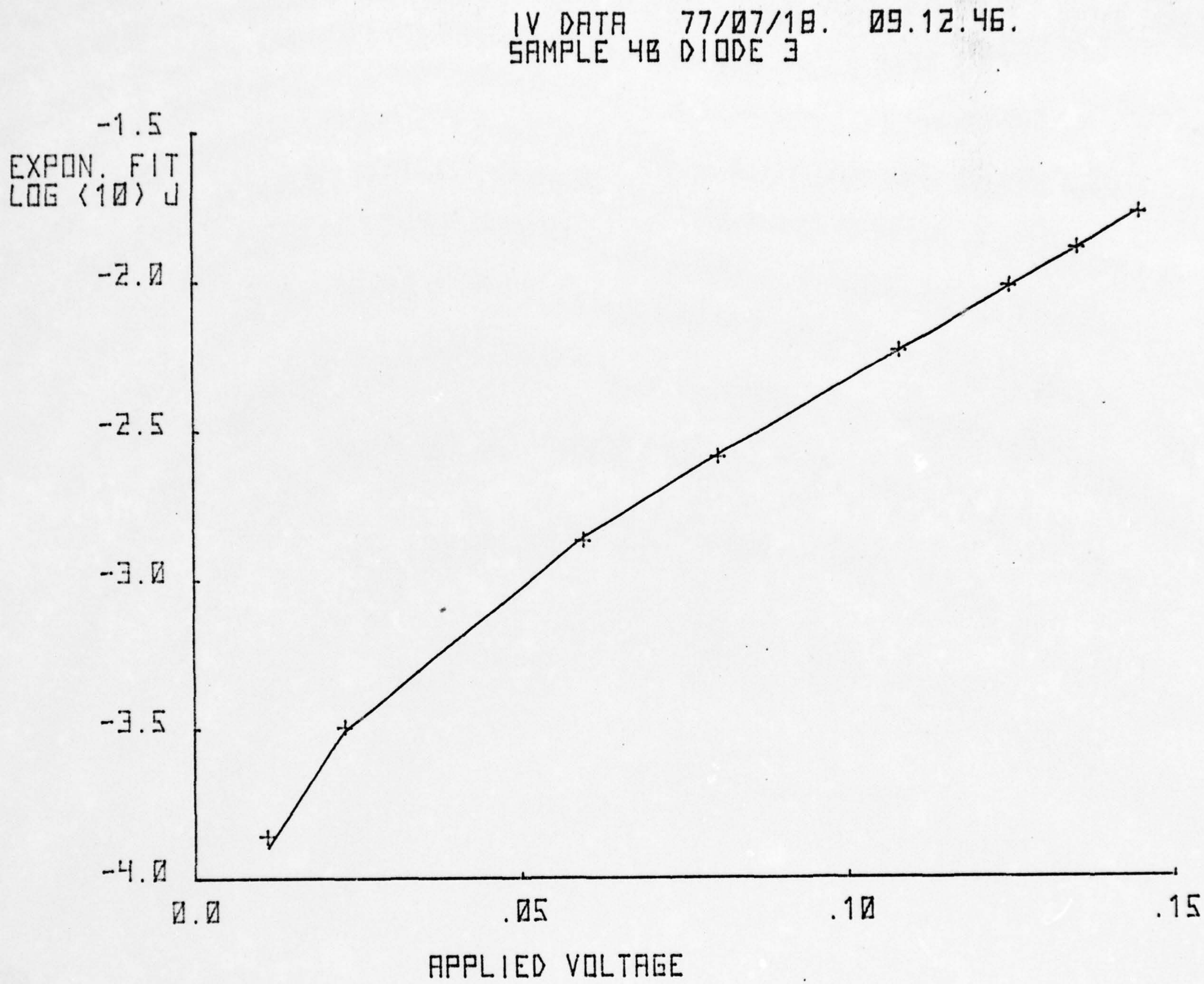
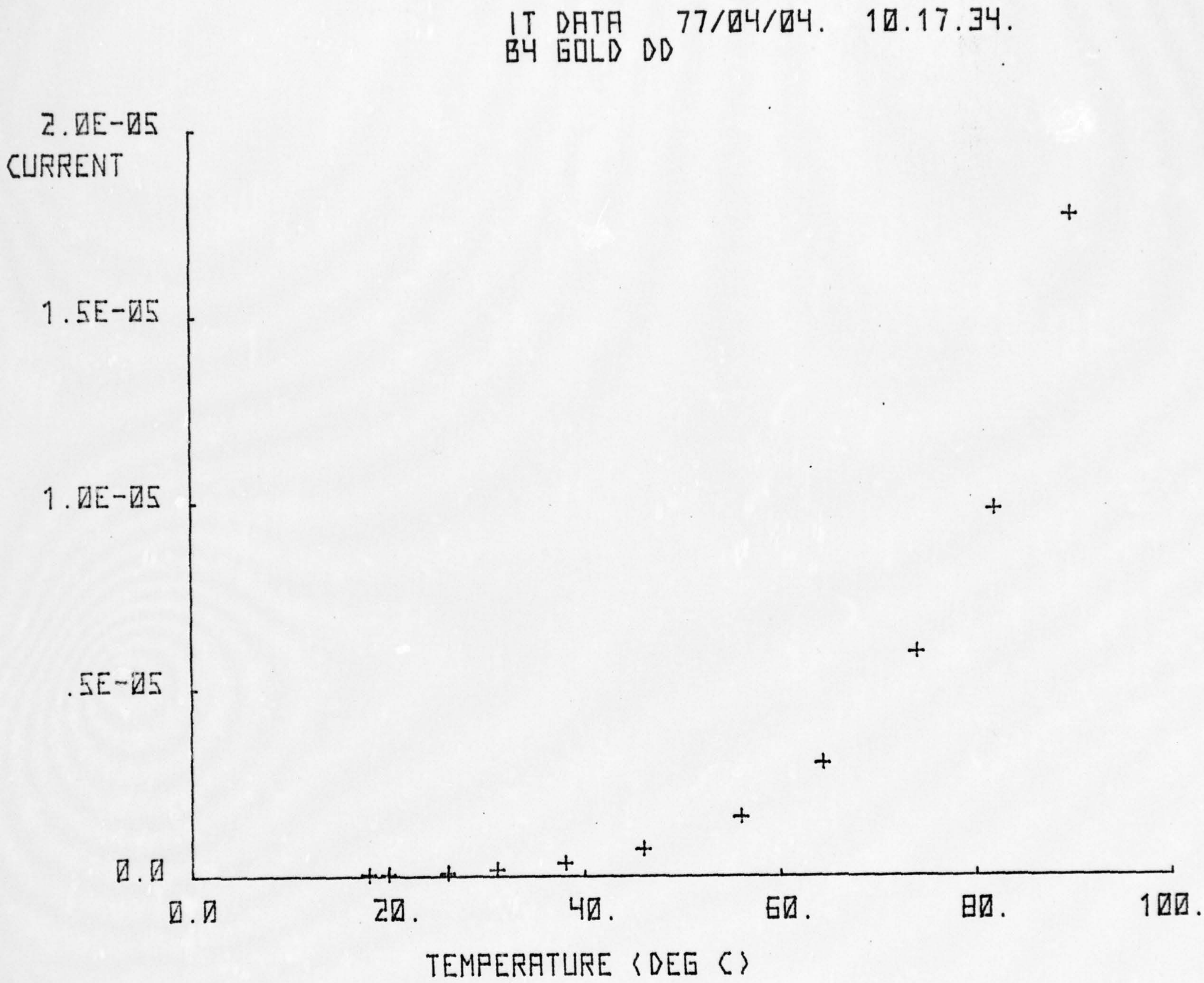

IV DATA 77/07/18. 09.12.46.
SAMPLE 4B DIODE 3
EXPON. FIT
LOG (10) J
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
0.0
.05
.10
.15
APPLIED VOLTAGE

Fig. 8



IT DATA 77/04/04. 10.17.34.
B4 GOLD DD
2.0E-05
CURRENT
1.5E-05
1.0E-05
.5E-05
0.0
0.0
20.
40.
60.
80.
100.
TEMPERATURE (DEG C)

Fig. 9

B4 GOLD DD
77/04/04. 10.17.34.

MATERIAL GAAS AREA .06065500 MM↑2

VOLTAGE -.200 JUNCTION TYPE ABRUPT

IDEALITY FACTOR FROM IV DATA 2.220

T (DEG C)	I (AMPS)
18.0	4.94E-08
20.0	7.02E-08
26.0	1.03E-07
31.0	1.94E-07
38.0	3.62E-07
46.0	7.39E-07
56.0	1.59E-06
64.3	3.02E-06
74.0	6.00E-06
82.0	9.83E-06
90.0	1.77E-05

THE LINEAR CURVE FIT GIVES
I = (A*)*T↑2*EXP(Q/(KT)*VBI)*(EXP(Q/(N*KT)*V)-1)
WITH:
A* = 731.048
VBI = .6832

Fig. 10

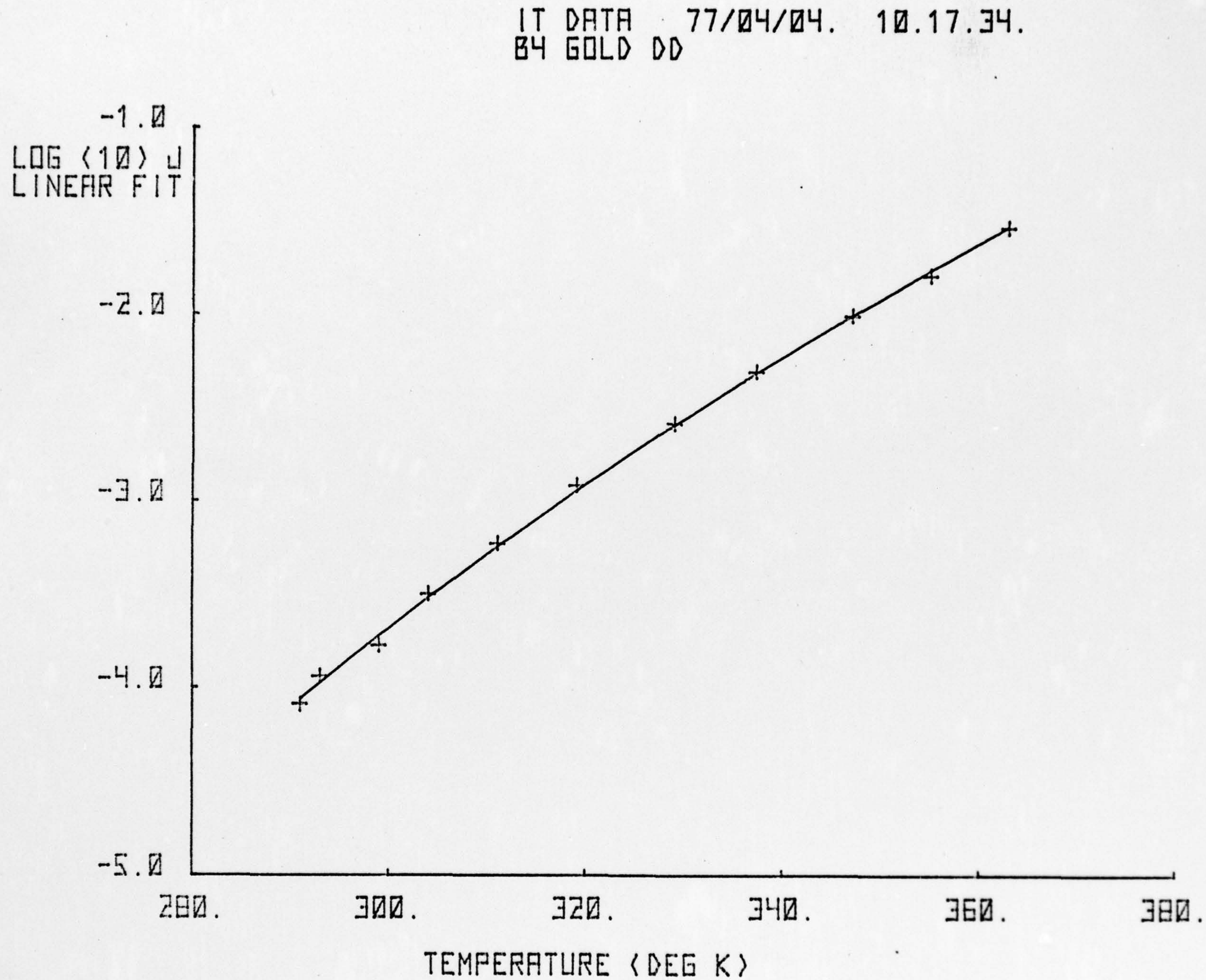

IT DATA 77/04/04. 10.17.34.
B4 GOLD DD
LOG (10) J
LINEAR FIT
-1.0
-2.0
-3.0
-4.0
-5.0
280.
300.
320.
340.
360.
380.
TEMPERATURE (DEG K)

Fig. 11

TABLE 2

Current-Voltage

Sample	No. Diodes	Exponential Curve Fit: Js (a/cm ^{2})	n	R(ohms)	ϕ(volts)	Linear Curve Fit: Js (a/cm ^{2})	n	ϕ (volts)	Metal
B4	12	4.98E-5	2.22	1.23	.6681	6.00E-5	2.42	.6631	Au
B4	2	3.45E-5	2.32	1.6	.6718	4.28E-5	2.54	.6664	Au (after mesa etch)
N19A	5	7.23E-5	2.44	0.77	.6582	7.22E-5	2.51	.6570	Au
N19B	9	7.38E-5	2.32	1.37	.6590	7.87E-5	2.48	.6570	Au
N19C	4	7.30E-5	2.22	2.77	.6603	7.74E-5	2.39	.6595	Au
RCA	2	1.07E-5	5.24	0.65	.7016	0.45E-5	4.38	.7235	Au
C1	2	2.82E-4	3.06	1.32	.6188	2.82E-4	3.28	.6117	Al
C3	2	5.62E-2	2.46	0.13	.4839	6.80E-2	5.72	.4909	Al
N20	3	6.65E-4	4.39	0.11	.6171	3.36E-4	3.62	.6314	Al

Capacitance-Voltage

Sample	No. Diodes	V_{bi} (volts)	N(cm^{-3})	Metal
B4	4	2.577	4.34E17	Au
RCA	6	0.584	2.49E15	Au
TI	2	3.448	2.86E18	Au
N20	4	0.781	5.18E17	Au

Table 2 (continued)

Sample	No. Diode	V_{bi} (volts)	$N(cm^{-3})$	Metal
B1	6	1.851	6.12E17	Au
C1	2	0.174	7.47E17	Al
C3	2	0.228	8.68E17	Al
B1	4	1.618	8.63E17	Al

Sample	No. Diodes	Current - Temperature		Metal
		$A\ (a/cm^2/{}^oK)$	ϕ (volts)	
B4	3	715.	.6843	Au
N19C	2	7433.	.7295	Au

a.) Because of current leakage effects the n obtained from exp (qV/nkT) is not close to 1 as found for a guarded structure.

b.) Represents the presence of any resistance in series with the Schottky diode. This is observed to be small.

c.) Samples N19A, B, and C were three pieces from the same wafer processed in the same way. Agreement of the average value of the parameters for several diodes from each wafer is good.

d.) Sample RCA has the lowest doping of any samples ($\sim 1 \times 10^{16} cm^{-3}$) and is observed to have the highest barrier height ϕ. This is felt to be related to leakage current as discussed below.

e.) The Aℓ samples are observed to give a lower barrier height as expected, but the difference is far less than predicted for the surface state free case. The Aℓ samples appear even more leaky than the gold.

f.) Although the C-V measurements give good agreement for the doping level, there is wide variation in the built-in voltage V_{bi}. On sample B1 the average V_{bi} for Al is less than for Au.

g.) There is a wide variation in the Richardson Constant value A in the I-T measurements. The course of the variation is again believed to be leakage current. ϕ is not sensitive to the value of A.

Objective 4

To date, only a matrix experiment on samples doped to mid-10^{17} cm^{-3} has been completed. Table 3 indicates the sample code and nature of preparation. The samples were from a polished lot purchased from Laser Diode Laboratories with a (100) orientation and a 1400 cm^{-2} etch pit density.

Table 4 lists the measurement results. The following observations are made:

Table 3

Sample	Cleaning	Metal
1A	$3H_2SO_4:1H_2O_2:H_2O$	Al
1B	Methanol-bromine	Al
1C	Methanol-bromine	Al
2A	Methanol-bromine	Al
2B	Methanol-bromine	Au
3A	$3H_2SO_4:H_2O_2:1H_2O$	Al
3B	$3H_2SO_4:H_2O_2:1H_2O$	Au
3C	$3H_2SO_4:H_2O_2:1H_2O$	Au
4A	$HCl:H_2O_2$	Al
4B	$HCl:H_2O_2$	Au

TABLE 4

Current-Voltage

		Exponential Curve Fit				Linear Curve Fit				
Sample	No. Diodes	Js(a/cm^2)	n	R(ohms)	Ø(volts)	Js(a/cm^2)	n	Ø(volts)	Metal	Comments
1A	4	4.72E-3	4.14	-.76	.5577	2.06E-3	2.72	.5781	Al	
1B	4	5.58E-3	5.88	-1.72	.5543	2.176E-3	3.15	.5834	Al	
1C	4	Curve fit on only 1 of 4 diodes							Al	Leakage Current too high
2A	6	No curve fit							Al	"
2B	3	1.33E-5	2.74	.46	.6496	9.28E-5	2.49	.6585	Au	Reference measurement
2B	2	2.01E-5	2.02	.46	.6984	2.16E-5	2.07	.6967	Au	Measured 5 days later
3A	2	No curve fit							Al	Leakage current too high
3B	5	3.50E-4	3.11	-.96	.6592	1.52E-4	2.64	.6671	Au	Wide range
3C	4	1.58E-5	2.82	-2.08	.7490	0.83E-5	2.98	.7507	Au	"
4A	4	8.54E-4	1.90	.83	.6032	7.92E-4	2.06	.6038	Al	
4B	4	3.99E-4	1.57	-.42	.6208	2.66E-4	1.36	.6314	Au	

Table 4 continued

		Exponential Curve Fit				Linear Curve Fit			
Sample	No. Diodes	Js(a/cm^2)	n	R(ohms)	Ø(volts)	Js(a/cm^2)	n	Ø(volts)	Metal
4B	4	2.28E-4	1.53	-.33	.6433	1.72E-4	1.40	.6515	Au After 3:1:1 etch to give mesa diodes.

Capacitance-Voltage

Sample	No. Diodes	V_{bi}(volts)	N(cm^{-3})	Metal
4A	4	.5650	7.24E17	Al
4B	3	.433	6.32E17	Au

a.) The most uniform and consistant data was obtained on samples 4A and 4B etched with $1HCl:1H_2O_2$ before metallization. This is reflected primarily in the low n values and the low standard deviation in the barrier height measurement (not shown). It is not possible at this time to separate the effects of leakage current and surface states on these parameters. A $3H_2SO_4:1H_2O_2:1H_2O$ etch to form diode mesas on sample 4B appeared to have no significant effect except for a slight increase in the barrier height value.

b.) Gold Schottky diodes have less leakage current than Al Schottky diodes. This is shown by the failure to obtain a curve fit for several Aℓ diodes and the lower n and J, values for Au when a comparision could be made.

c.) The data does not allow a good comparison between 3:1:1 and methanol-bromine for Al diodes. For the Au diodes, the two etchants gave different results. The 3:1:1 caused a wide variation in the results from one diode to the next on the same sample. The methanol-bromine gave more uniform values among diodes on the same sample, but showed a tendency to have less leakage current with time (lower J_s and n and higher $\emptyset$ on sample 2B-linear curve fit). This appears to be quite significant and will be watched closely on the mid-10^{16} cm^{-3} matrix evaluation.

d.) The capacitance-voltage data on 4A and 4B gave good agreement on the sample doping level but the built-in-voltage V_{bi} value is questionable because of the still relatively high leakage current.

Objective 5

This objective was not reached under this grant.

Personnel

Dr. Bruce P. Johnson, Associate Professor, Electrical Engineering, University of Nevada, Reno.

Mr. Lawrence Butcher, M.S. Candidate in Physics. Part of this work reflects his thesis topic.

Mr. Daniel Tang, M.S. Candidate in Electrical Engineering. (Work not supported by this grant.)

Scientific Papers

None at this time.

Scientific Interactions

Telephone and written communications with:

Dr. Chern Huang, Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio 45433

Ms. E. Tarrents, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433

Informal Communication with individuals at:

1. National Science Foundation Workshop on "Needs for a National Research and Resource Center in Submicron Structures" (May, 1976).
2. Electrochemical Society Fall Meeting, Las Vegas (October, 1976).

Inventions or Discoveries

None.

Relevant Information

This grant was very instrumental in establishing the measurement/analysis capability described above at the University of Nevada. It is the goal of the principal investi-

gator to see this work continued and to interrelate the "ideal" material measurements world of the physicist with the real word measurement situation of the engineer.

Appendix 1

SAMPLE PREPARATION

The GaAs wafers were either purchased already polished or polished in the laboratory (final polish was methanol-bromine). The wafers were solvent cleaned and 4000 Å of gold-12 wt% germanium alloy evaporated on the backside. The contacts were fused for five minutes at 525°C in purified argon. The samples were then cleaned in the appropriate etchant and immediately loaded into the vacuum chamber. Evaporation was at greater than 10 Å/sec. using a liquid nitrogen trap and a pressure less than 2×10^{-6} Torr.

Appendix II

Computer Programs

To reduce paper work and mailing weight only one copy of the C-V, I-V, and I-T computer program has been sent to:

Capt. Wayne R. Steinbach
AFOSR/NE
Bldg. 410
Bolling AFB, D.C. 20332

Additional copies are available on request from the author of this report.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

GaAs, Schottky barrier height, Transferred electron devices, leakage current.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The electrical properties of gold and aluminum Schottky barrier contacts have been measured on GaAs as a function of preparation. Current-voltage, capacitance-voltage, and current-temperature measurements have been made to examine the effects of methan-

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20.

ol-bromine, sulfuric-hydrogen peroxide-water, and hydrochloric-hydrogen peroxide surface cleaning. Generally, a guard ring approach is used to reduce leakage currents. In this case, no guard ring is used and an attempt has been made to evaluate leakage by the computer evaluation of the equation parameters. Results-to-date indicate that the gold gives a slightly larger barrier height than aluminum, that hydrochloric-peroxide gives the least leakage current, and that under some preparation conditions, the leakage varies with time.